AIRLINE MAINTENANCE: A PROPOSAL ENVISIONING DIGITAL TRANSFORMATION

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Abstract

The aviation industry has been investing heavily in technology since its inception. These investments have primarily been driven on the manufacturing side of the industry. Not only must the product digitally evolve, so to must the back office of airlines. Aircraft maintenance is an essential branch for airlines that must renew and adapt to be more efficient, provide greater reliability, reduce costs, and increase availability of the aircraft for revenue service. Therefore, the proposal is to depict today's heavy maintenance process and propose a near future picture, aided by cyber-physical systems, which will digitally transform the heavy maintenance process to reduce aircraft downtime.

1 Introduction

The digital economy is becoming more evident in the movement among different industries through transformations provided by new technologies. Technological developments in areas such as augmented reality, cloud computing, artificial intelligence (AI), big data, internet of things (IoT), and others, are redefining customer expectations by bringing innovation not only into everyday life but also facilitating the way people work.

By disrupting existing processes and operating models, digital innovations have been reshaping businesses. This process is called "digital transformation" and has impacted economies by adding value to industry productivity while at the same time bringing new challenges to industries and policy-makers [1].

Digitization has been happening in different sectors such as banking, telecom, manufacturing, and pharmaceutics. Moving beyond the concept of digital transformation to actual application is a difficult task, especially in terms of what digital technology enables and the opportunities they offer to reduce costs and increase profits simultaneously. Thus, not all players have achieved a high level of digital maturity.

One sector that has been embracing digital transformation is the airlines. Through extensive investments in innovative services, airlines have improved the user experience and improved customer relations. Transforming flights into personalized travelling experiences with an interface that makes the airline stand out in a highly competitive market is the challenge faced by the sector [2].

One of the important operational costs for an airline is maintenance. Besides the costs related to performing maintenance tasks, which are inevitable, the process of performing heavy maintenance requires removal of an aircraft from operation for days or even weeks, losing valuable revenue. Performing scheduled maintenance on aircraft is unavoidable. The more an aircraft flies, the more maintenance it needs to ensure reliability and safety for passengers.

Hence, the question of how to minimize airline down time during heavy maintenance is an important issue for airline maintenance management groups that aim to reduce maintenance costs and increase operational availability.

Keeping this issue in mind, the objective of this paper is to depict the current airline heavy maintenance process and propose a digitally transformed picture that covers near to long-term solutions. For this to be accomplished, incremental innovations in today's general maintenance process will be suggested, leading to potential reductions in heavy maintenance downtime in the near future.

In order to draw an initial picture of the process, this review will analyze one of Brazil's largest airlines with the intent to provide positive contributions to the airline's maintenance management group.

Following this review of the airline's current process, an analysis considering new ways of performing heavy maintenance, using a cyber-physical system (CPS), will be reviewed to determine a potential future state. This will highlight changes to the existing heavy maintenance process leading to a decrease in the days the aircraft is removed from service due to heavy maintenance and thus linking the physical and cybernetic world.

This work consists of this section, an introduction, followed by section 2, a literature review of digital transformation in airlines and maintenance, section 3, the research design, the results and discussion in sections 4 and 5, and a conclusion in section 6.

2 Digital Transformation in Airlines

2.1 The Digital Transformation

The world is constantly changing and transforming, in part due to new technologies. Every year, thousands of new technologies arrive in the marketplace and into the hands of consumers resulting in the public having better digital solutions in their own homes than at work [3].

Customers today are expecting more from companies, desiring not to wait for a response from their expressed demands, but anticipating their future needs before they realize them [4].

The digital transformation strategy is focussed on a different approach to IT strategies. It arrives at a business-centric perspective to new technologies, and enables transformation of processes, products/services, and facilitates the lives of workers, supervisors, and managers through organizational aspects change [5].

Discussions about digital business strategies offer a base study for the possibilities and effects caused by digitizing firms. Looking forward, to succeed in the digital transformation, leading companies intend to deliver greater customer interaction and collaboration by focusing on reshaping customer value propositions and transforming their operations through digital technologies [6].

Moreover, digitization depends not only on development of technology but also on leadership and innovation management. The approach should utilize operational and functional strategies that allow for overall corporate strategies of transforming to be achieved. A combination between technology and leadership could result in three main areas of digital transformation: customer experience, operational process, and business model [3].

2.2 The Benefits of Digitization

Digital mature companies achieve performance gains by combining two dimensions - digital intensity and transformation intensity. The first is achieved by investing in digital initiatives, changing how the organization operates through technological improvements related to internal and external clients', sometimes resulting in new business models. The second is achieved by creating the leadership capabilities needed to keep the firm moving forward during the digital transformation [3].

Azhari et al. (2014) proposed a maturity model for digital transformation to clarify where an organization is situated by depicting five categories of digital maturity (unaware, conceptual, defined, integrated, and transformed) and providing guidance for increasing the maturity level thought eight dimensions (strategy, leadership, products, operations, culture, people, governance, and technology).

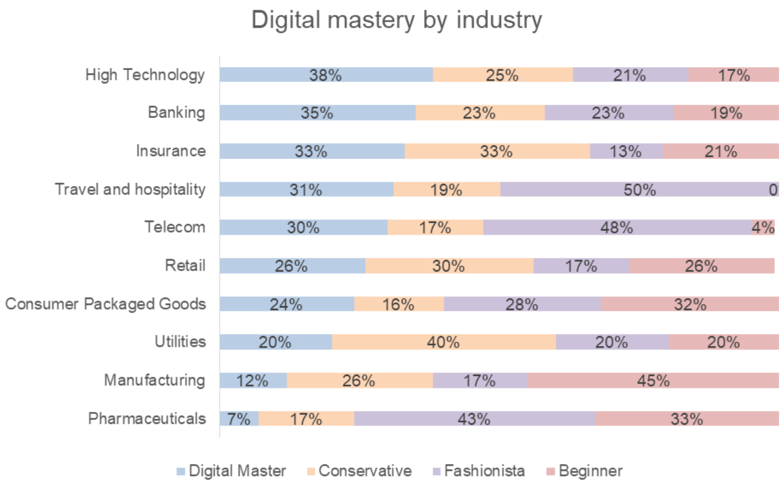
Digital maturity matters because the investments and risks taken by organizations that adopt this digital transformation movement must be justified through increased revenues, profits, and/or market share. According to Oestreicher-Singer and Zalmanson (2013), community-based digital business models could create profitable revenue streams in times of "freemium" business models.

2.3 The Digital Future of Airlines

Since the advent of the web, the aviation industry has been exposed to digital competition. These organizations have launched important technological features and have advanced the dispute. Fig. 1 highlights the digitalization of different industries. Under "travel and hospitality", the aviation industry has 31% of Digital Master companies, 50% of Fashionistas and the others are Conservative companies (19%).

Airlines are grouped under the "travel and hospitality" industry and is the only industry that does not have beginners in digital maturity.

Fig. 1. Digital mastery by industry [3].



In 2013, one of the richest men in the world, the famous investor Warren Buffett, called the commercial aviation industry a "death trap for investors". Three years later, he spent more than US$ 1.3 billion in commercial air carrier stocks, highlighting the big picture of the new direction the aviation industry is taking [2].

The extensive investment in digital innovation prepares organizations to reach such improved levels, but not all of them have invested in transformation management, placing the majority as fashionistas. Notwithstanding, similar intensity of investment in leadership could drive improvements in the travel and hospitality industry through ways in developing more coordinated and efficient approaches, adding value to their digital transformation [3].

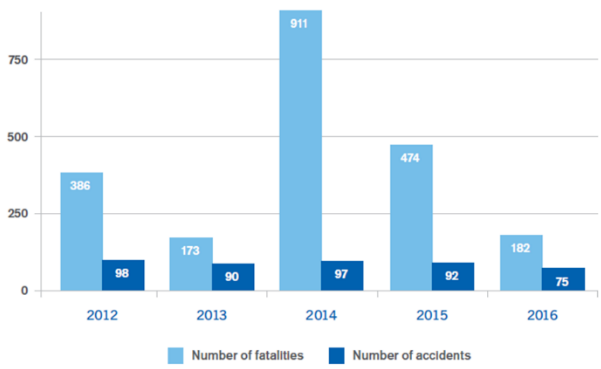
Conservative airlines should invest in technology once they achieve a level of management maturity necessary to lead a transformation with a strong unifying vision deployed by a well-defined governance and corporate culture. However, according to Westerman (2012), conservatives are sceptical about the value brought by new digital trends, causing them to miss valuable opportunities.

Back offices of airlines should also transform to keep up with the rest of the organization. Operations, maintenance and engineering, net schedule, and other groups should also invest in service or strategic innovations.

2.4 Aircraft Maintenance of Today

The air transport industry plays a major role in global economic activity and development. The maintenance of aircraft is a key to successfully assuring reliability and safe operation globally. In the context of major civil aviation growth in the last decade, the maintenance of aircraft has become crucial to keeping the number of accidents at a minimum in the sector. The statistics presented in Fig. 2, shows a decrease in both the number of accidents as well as the accident rate. The number of accidents in 2016 was 18 per cent lower than the previous year as seen in Fig. 2, and at the same time, the global accident rate dropped from 2.8 to 2.1 accidents per million departures [7].

Fig. 2. Accident records, 2012–2016 scheduled commercial flights [7].



An aircraft is made up of millions of parts comprised of complex, redundant systems to ensure safety and reliability of the product. Maintaining these systems costs an airline time and material in conducting thousands of scheduled tasks that must be performed at different intervals, as well as unexpected, or unscheduled tasks. Some of the current concepts of maintenance types include:

(1) Preventive maintenance which comprises recurring, or scheduled maintenance tasks accomplished in order to prevent unscheduled downtime and premature system failures;

(2) Corrective maintenance for unexpected failures, or unscheduled tasks unless previously identified through the efforts of reliability engineering that work to improve or repair the system and thus eliminating the failure before it occurs; and,

(3) Predictive maintenance that traditionally uses a maintenance management tool, that limits or prevents unscheduled downtime and/or catastrophic failures through regular monitoring of operating condition indicators and provides data required to ensure the maximum interval between repairs and inspections [8].

Focusing on preventive maintenance, the classifications of tasks performed on an aircraft mostly consists in: inspections, functional tests, operational tests, component replacement, component restoration or discarding, lubrication, servicing, and cleaning.

60% of the total content of scheduled maintenance is related to inspections. These inspections could be superficial external examinations or more complex internal examinations. The later could require extensive preparation and access or require a wide area to inspect, resulting in a large consumption of labor hours to perform. An example of a more complex internal examination requiring deep access into the aircraft is the fuel tank valves and pumps that are periodically checked to identify leaks or malfunctions. Similarly, another more complex examination of a wide area to inspect is the fuselage that is examined to identify corrosion or lightning strikes.

The remaining 40% of scheduled maintenance tasks is split between functional and operational tests related to electronic, hydraulic, and other systems and component replacements, moving parts lubrications, cleaning and servicing. All of these tasks ensure the safe reliability and operation of the aircraft.

All regularly scheduled maintenance tasks are performed in two different environments (a) line maintenance that is performed during overnights when there is no need to remove the aircraft from operation, usually requires between 6 to 10 hours of ground time, and does not need extensive disassembly; (b) heavy maintenance or hangar maintenance that is performed inside a hangar and removes the aircraft from operation, potentially requiring from 1 to 40 days of ground time, with extensive access and disassembly required to accomplish.

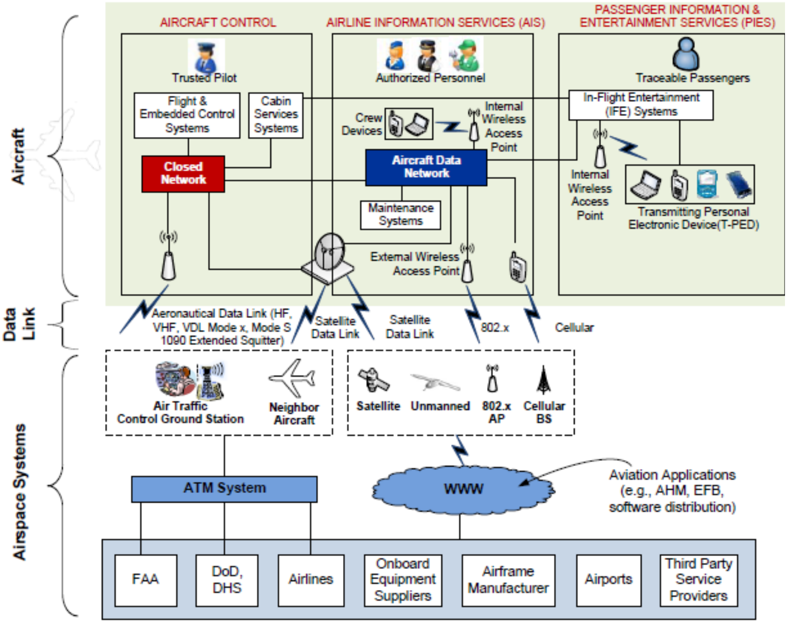
To control and perform these maintenance tasks, airlines utilize intervals provided and defined by the aircraft manufacturer. Most airlines group tasks defined by the manufacturer in order to facilitate maintenance planning and reduce the number of days out of service and requires coordination with operations to ensure these maintenance opportunities do not impact aircraft availability, especially during peak seasonal needs. Despite the enhanced technology embedded in aircraft systems, most maintenance is still performed through very traditional ways, and, as previously stated, requires extensive labor hours to perform resulting in the aircraft not being available for use for many days.

2.5 Digital transformation of maintenance

The system of an airline company is very complex. It integrates a wide variety of subsystems that are related to the aircraft and the airspace systems. The aircraft operation, the airline information services, the passenger information and entertainment services are all integrated into the environment surrounding the aircraft through a data link [9]. Fig. 3 provides an overview of a few system relationships in the airline world and the integration between the subsystems.

Maintenance is a subsystem inside the airline system in Fig. 3, and it is location inside the aircraft group, under airline information services (AIS) and connected to the aircraft data network. This maintenance system box can be expanded into many other physical and digital processes.

Fig. 3. E-enabled aircraft and its integration with airspace system [9].



Improvements in maintenance processes would aid air carriers in ensuring continued reduction in aircraft incidents. Thus, it is vital to fly towards the benefits that air carriers could achieve through digital transformation. Benefits brought by technological advancements – IoT, augmented reality, big data and cloud computing can aide in moving in the right direction.

3 Research design

As stated in the introduction, maintenance management teams in airlines seek for reducing maintenance costs face the issue of minimizing down time in heavy maintenance. In order to answer this question, the proposal is to trace the maintenance services requirements of an airline looking for the process of performing maintenance. Listing the steps, labor hours, and ground time impact related to each phase. After that, the proposal is to offer a solution through the lens of digital transformation, drawing a picture with incremental innovations that would contribute to solving this issue. The following steps were taken to achieve this paper goal.

3.1 Sample selection

There are different approaches to sample selection methods. As Marshall (1996) said, there are three examples of common sample selection methods, convenience sample, judgement sample, and theoretical sample. The method chosen for this work is the judgement sample, which consists in selecting the most productive sample to answer the research question, based on the researcher's practical knowledge of the research area and available literature. The advantage of this method meets the requirements of this work since the subjects (Brazilian airlines) have specific experiences [10].

Prior to the 90s, air transportation in Brazil was very regulated and restricted. Subsequently, the government started to open price regulations and dictate the way airlines must operate in Brazil. Today, one of the only governmental limits is the participation of foreign companies in national airlines, which is limited to one fifth (20%) of equities through the Brazilian Aeronautical Code [11]. As a result, the limit imposed by the Aviation Code is a barrier for international companies to be present in the Brazilian domestic market, which more than doubled in the last ten years [12].

In Brazil, there are four major airlines that together represents more than 98% of the passenger transportation market. The company that transported more passages in 2016 was GOL (34.1 % of the total), followed by Latam (32.3 %), Azul (21.9 %) and Avianca (10.4 %) [13]. In order to study the maintenance operations of a Brazilian aviation business, and how the digitization may innovate the ecosystem of the sector, GOL's maintenance process was chosen to be analyzed. In 2016, GOL was ranked as the leading airline in the Brazil, based on domestic market share [13]. Consequently, it can be considered as a representative sample for the purpose of this paper.

3.2 Data collection

To collect the date and understand the process, a review of the maintenance flowcharts provided by the company is proposed.

The data collection will be conduct by a review of the latest maintenance flowcharts provided by the company, depicting the steps drawn in these maintenance processes. Observing the method by which the airline regularly performs scheduled heavy maintenance on its aircraft from when the aircraft is removed from operation and sits it in the hangar, until the moment the aircraft is release to service after being signed by the authorized inspector.

Actual maintenance data will be provided by the GOL maintenance team. In addition to GOL provided data, a literature review of available technology to digitally transform maintenance for airlines will be included using market data from organizations offering products that fit this research proposal, such as systems that provide data analysis to actuate in predictive maintenance of aircraft, ancillary systems that support paperless projects with digital documents, cloud storage and e-signature, web based system that helps to manage MRO companies.

3.3 Data analysis

The analysis of the data will be done considering the current impacts these maintenance processes are causing in the ground time of heavy maintenance checks performed by the airline. Similarly, the validation will consider the experience of the company in developing the maintenance flowcharts provided.

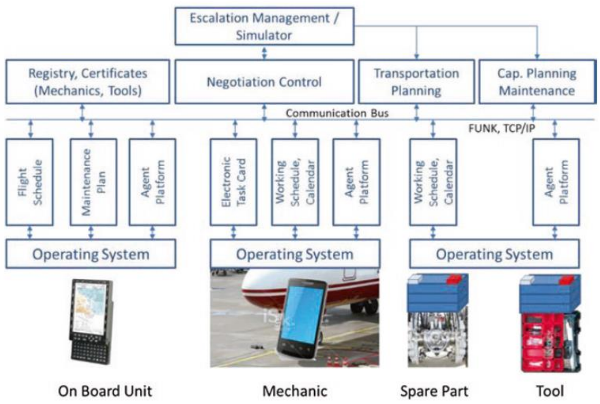
Focusing in the suggestion of an innovative maintenance process, the analysis starts by describing today's picture by reviewing the maintenance process to comprehend the systems requirements. This review will then allow the identification of weaknesses that could be improved through the use of digitalization.

After underlining the points inside the maintenance process from the airline, the proposal is to use a tool from systems engineering called Systems Modelling Language (SysML) in order to develop the model. SysML enables a more complete modelling of software/hardware systems and facilitates the top-down approach of traditional systems engineering using the block as its primary entity [14].

Drawing the model is a facilitator to understand the foundations of aviation maintenance problems and how to contribute to reduce the ground time for heavy maintenance in the near future with the advent of digitalization. Proposing which of the system blocks, interconnections and relationships between the physical and the cyber world could be applied to the existing heavy maintenance process.

A practical example, given by Trentesaux, D. et al (2015), of aircraft maintenance using a CPS is from the MRO planning perspective: an aircraft on the way from base A to base B recognizes a problem and has to take under consideration, that even though the mechanic and the spare part are available in base B, an expensive required tool is not. Thus, with the help of software, a suitable tool in base C is identified and processed through a regular flight from base C to attend base B on time for the maintenance be accomplished. This interaction between the physical and the cyber world is illustrated in Fig. 4.

Fig. 4. Architecture of CPS in an aircraft maintenance system [14].



4 Results

The current picture of the airline heavy maintenance process is translated from the flowcharts provided by the company into main steps. These phases are necessary inputs to drawing a picture of where with the maintenance system is today.

4.1 Airline heavy maintenance process review

When an aircraft is manufactured, its maintenance countdown starts. There are three major counters calendar days, flight cycles (that is the number of departures and landings) or flight hours. Based on these three counters, heavy maintenance checks containing scheduled tasks can be created.

The process starts with demand planning of the heavy maintenance check. Once the aircraft reaches the planned date for heavy maintenance, the aircraft is induced in the hangar. At this point, the maintenance is divided into thirteen phases that may be performed in parallel. Fig. 5 presents an example of a heavy maintenance process flow that visually illustrates a B737-800 heavy maintenance check.

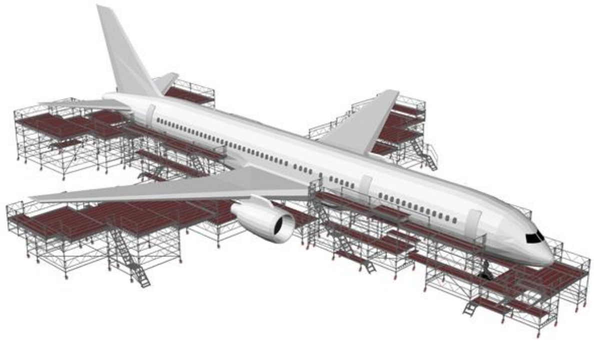
Fig. 5. Heavy maintenance flow chart, delineating the different phases of the process (elaborated by the authors).

Phase	Start	End	01	02	03	04	05	18	19	20	21	22	23	24	25	26	27	28	29	30
1	01	01	X																	
2	01	02																		
3	02	03																		
4	03	03			X															
5	03	03			X															
6	04	29					...													
7	18	29																		
8	18	18						X												
9	19	29																		
10	30	30																		X
11	30	30																		
12	30	30																		
13	30	30																		X

The heavy maintenance flow chart shown in Fig. 5 can be further sub-divided into smaller and more detailed steps, reaching the facet of each maintenance action that must be performed. For the purpose of this paper, the list of phases in Fig. 5 were mapped as follows:

1. Pre-docking: site preparation to facilitate access to elevated areas, arranging platforms, scaffoldings, stairs and docks around the aircraft as illustrated by Fig. 6. The full process can take a few hours;
2. Preliminary inspection: the aircraft is inspected in order to identify visual conditions of structures and systems. Structural damages that can occur in service is verified, such as scratches, buckling, dents, lightning strike damage, etc. Also, visual conditions of systems failures is verified, such as leaks, broken parts, missing parts, etc. This phase can also take an entire day to be accomplished;

Fig. 6. Aircraft docking illustration [15].



3. Open access and panels: gain access to deep areas that must be inspected such as stringers, ribs, and spars. For this, it is necessary to remove panels, galleys, lavatories, floor, sidewalls, and overhead bins. The open access phase can take between one and three days;
4. Electrical and hydraulic power off: in this phase electrical and hydraulic power are turned off to ensure safe maintenance of systems that may be pressurized or cause electric shock. Turning off these systems usually takes minutes;
5. Tank defueling: consists of empting all fuel tanks (wings, central) to gain access to the interior fuel area. This step takes a few hours;
6. Task accomplishment and findings correction: at this point, the aircraft is ready to receive the technicians who will perform the maintenance tasks. It is this phase that takes the most ground time and labor hours to be completed. This step can be divided into four pieces: (6.1) inspections, (6.2) task accomplishment, (6.3) opening and (6.4) closing findings. The long duration is due to the maintenance tasks defined by the manufacturer that must be performed and all open issues to be corrected in order to ensure that the aircraft will return safely to operation. Depending on check composition and aircraft age, this phase can take between two to thirty days.
7. Close access and panels: installation of all the panels, floor, sidewalls, galleys, lavatories and overhead bins that were removed for inspection. In addition, this action must be carried out with extreme

care, ensuring that no tools or equipment are left inside the access and that all panels are properly closed. For this reason, an inspection is conducted in parallel to this action. Thus, depending on the number of disassembled panels, this step can take from one to five days.

8. Tank fueling: consists in filling all fuel tanks (wings, central). This phase can take a few hours;
9. Operational tests: this procedure is required to ascertain only that a system or unit is operable. These tests should require no special equipment or facilities other than that installed on the aircraft and should be comparable to the tests performed by the flight crews. The entire phase can take five days once it starts during the end of task performance and findings correction phase;
10. Flight test: in the occurrence of primary control surfaces adjustments or sometimes dual engine replacement, a flight test is mandatory to ensure that the aircraft meets all applicable safety and performance requirements. This phase is entirely dependent on operational issues and usually takes three hours between taxing and performing the flight;
11. Daily and Service checks: checks performed during the last day of the heavy maintenance check and comprises tasks of very low complexity that are executed at a high frequency of repetition, these tasks are related to the checking of routine items such as wheels, brakes, engine oil, potable water and waste, among others. Its duration is about 5 hours depending on the aircraft.
12. Final inspection: the aircraft is inspected in order to identify visually its final conditions. Structural damage that can occur during the maintenance period is verified. Also, visual condition of system failures is verified. This phase also takes an entire day to be accomplished and is the last barrier to avoid post maintenance incidents or accidents during operation;
13. Release to service: this step is the final signature releasing the aircraft to service, by ensuring to the aeronautical authority that the maintenance was performed, and the aircraft is ready to return safely to operation. It occurs right after the final inspection.

4.2 Systems engineering analysis of the maintenance process

The heavy maintenance process review flow chart defines a range of steps that directly impact the ground time of the heavy check. The more complex the step, the more time it takes in the flowchart.

Aiming to improve the process visualization and contribute with an answer for reducing heavy maintenance visit ground time, the phases regarding the procedure of heavy checks were transformed in a system aided by SysML in Fig. 7. This system delineates the relationships between the sub processes and tasks serving as a map to guide the discussion on how to use CPS to achieve incremental changes in the current heavy maintenance flowchart.

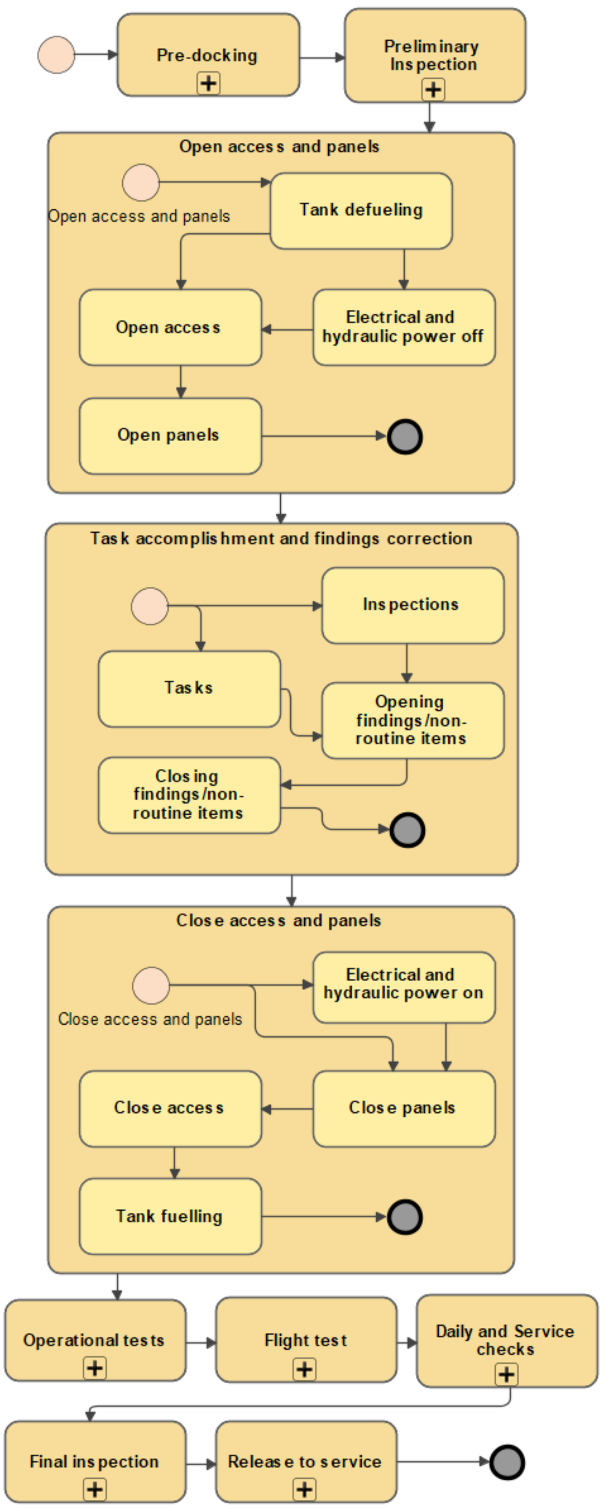
Observing Fig. 5 and Fig. 7, even small improvements in short duration phases could reduce one day in the heavy maintenance check duration. This one day in a large fleet, such as GOL with more than one hundred aircraft, could result in a significant increase in aircraft availability and passenger revenue.

To reach the next level of performance, it is essential to use technology. Proposing existing solutions of devices and services it is possible to reduce one day or more in heavy maintenance phases that impact total ground time.

5 Proposal of a new model of maintenance process

The proposal of a new model will be addressed with the aid of CPSs remediating the problem in three different time frames: a short-term innovation by implementing technologies that already exists, a medium-term innovation through technologies that are under development, and long-term innovation by pointing areas where new technologies would provide additional improvements.

Fig. 7. System depicting the view of today's heavy maintenance process using SysML (elaborated by the authors).



In terms of a short-term time frame, there are many possibilities to implement software capable of mining big data related to labor hours used to accomplish heavy maintenance tasks. Using this information to develop new methods of performing tasks will contribute to reducing labor hour usage. This labor hour reduction could indirectly impact the ground time of the aircraft or, even in small portions, free skilled labor to work areas that have more demand.

For the medium-term progress, looking closely at the inspection phases in the beginning of the flow, the two days of preliminary inspections (phase 2) is proposed. If this inspection time is reduced to one day in every maintenance visit, it could represent a significant decrease in the total days out of service, depending on the fleet size. Preliminary inspection is basically a visual inspection of the aircraft structural conditions and apparent systems damage. The use of drones' technology would represent an incremental innovation. It could contribute to reduce the workload and facilitates the inspection process. Flying around the aircraft caring sensors to film and interpret unusual conditions is faster than walking around.

The aim for long-term improvements would be through new technologies by focusing on the longest phase in the process, identified as the task accomplishment and findings correction (phase 6), where in a 30 days heavy check, 90% of the total time is spent with this phase. Reducing the time of this phase seems tempting. However, this phase represents an enormous challenge as technologies may not exist or techniques may not be realized at this time. The idea proposed is to use graphene circuits to cover internal or external structures. Graphene circuits can serve as an indicator of cracks, dents and other damages that, after deforming the circuit, would indicate its position and anticipate the need of structural repairs prior to the maintenance check.

6 Conclusion

Among the airline market there are different systems that provide improved efficiencies through CPS. Examining the heavy maintenance process more closely, it is also possible to point out systems which bring incremental innovations that increase productivity in the short and medium term, ultimately reducing ground time spent in the hangar. Efforts in developing new cyber-physical systems can enable disruption in the way maintenance happens today, predicting the need for maintenance, warning, or even making decisions based on safety. All of these efforts will lead to ground time reduction.

Technologies responsible for digitization, such as those mentioned in this paper, are bringing improved efficiencies to heavy maintenance processes, resulting in increased profits for airlines. The wave of digital transformation is upon us and it is clear that this transformation will also improve the methods used in the heavy maintenance management arena.

A future study is proposed to more thoroughly investigate the impacts of the incremental innovations discussed in this paper in the short and medium term, and how disruptive innovation could change the way aircraft are maintained.

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